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## Prefabricated elements and structures: Developments, tests and experiences.



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### ABSTRACT

Danish concrete structures are often built with prefabricated elements, joined together on the site and this provides a large challenge to constantly improve and optimize the elements, the joints and the models. DTU Byg has been active in the development, testing and modelling of new elements, joints and models and a number of results and experiences are presented in the paper.

**Key words:** Reinforcement, prefabricated elements, joints, testing.

### 1. INTRODUCTION

The design and construction of new buildings, houses and offices in Denmark will often use prefabricated elements, joined together on site to create complete loadcarrying structures. There is a constant interest in producing less expensive elements, in using fewer of cheaper materials and in developing and documenting easier, faster to implement onsite and more robust joint designs. The joining represents also one of the largest risks of faulty execution, which could endanger the structural safety. The Danish Technical University's Department for Civil Engineering (DTU Byg) has been active in development and documentation of such new element and joint designs in recent years.

The development of deck elements has focused on superlight SL-deck element /Hertz, Castberg and Christensen, 2014/, /Herts, 2013/, /Christensen and Hertz, 2012/, which resulted in the spin-off company Abeo, where production has already begun, however, there has also been substantial activities in design of wall elements and in design of joints between walls.

### 2. PREBRICATED WALL ELEMENTS

Prefabricated walls are reinforced, but there are some discussions about the amount of reinforcement required: Should walls be normally reinforced for bending or should they just contain the necessary amount of reinforcement to transfer loads and provide a fair distribution of cracks. Many Danish producers prefer the concept of lightly reinforced walls, where loadcarrying capacity for eccentric, vertical loads in combination with wind loads is ensured by the concrete's tensile strength as described by EN 1520. Reinforcement is in such designs only used for distributing shrinkage cracks and ensuring safety during transport and erection and will often consist of a reinforcement mesh of  $\phi 4\text{mm}/250\text{mm}$  (often of class A according to EC2) in the middle of the cross-section. This may be combined with additional reinforcement of class A or B around windows and doors, just as some sections as e.g. integrated beams over windows or doors may require more reinforcement.

It would, however, be a significant benefit if such lightly reinforced walls could have some of the same advantages as more heavily reinforced walls have, e.g. a possibility for using yield line theory for evaluating the capacities against transverse loads.

Three teams of project students /Franck and Odgaard, 2012/, /Bresemann and Odgaard, 2012/, /Sadiki and Reenberg, 2013/ at DTU Byg have therefore tested and evaluated lightly reinforced walls, exposed to transverse loads. The test walls (30 in total) were all 2,6 m x 4,0 m, with a thickness of 100 mm and were produced by EXPAN. The test setup at DTU Byg (Figure 1), supported the wall on all four sides and loaded it from behind by airbags.

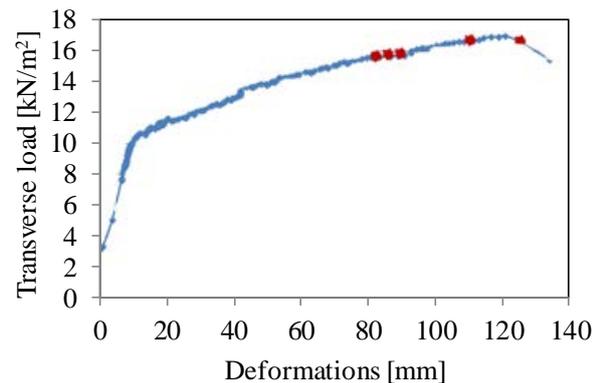


Figure 1 – Marking cracks in a tested wall element J and the load-displacement curve. Red starts indicate rupture of reinforcement /Sadiki and Reenberg, 2013/, /Youtube, 2013/.

The tested element designs covered lightly reinforced, lightly reinforced with additional, more concentrated reinforcement in specific zones (around the windows) and normally reinforced walls. It was found that yield lines develop in all cases, but that reinforcement tended to rupture before the peak load is reached (Figure 1), especially in the cases using class A steel or very low reinforcement amounts. This makes the use of the yield line theory dubious in such cases. Distributed reinforcement (mesh) and additional reinforcement in zones could, however, be combined in the estimation of loadcarrying capacity. Predictions from the yield line theory were lower than corresponding experimental capacities, probably due to the effect of large displacements. Large displacements increase load-carrying capacities to an extent, difficult to estimate by simple methods, but should be possible by numerical methods.

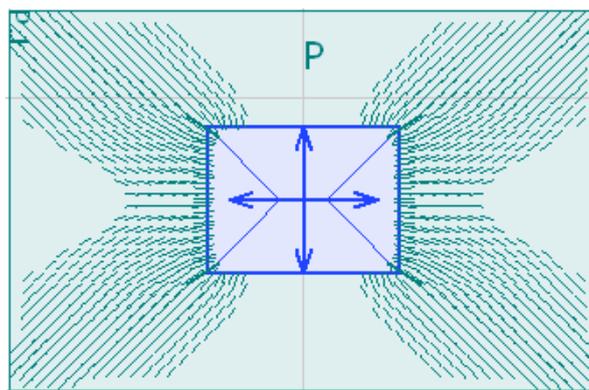


Figure 2 – Simulation of crack pattern in element J with Strusoft /Sadiki and Reenberg, 2013/.

Initial attempts to carry out such a numerical simulation with potential cracks and potentially large deflections have been made with the commercial program StruSoft. This was found to give a fairly good prediction of crack patterns (Figure 2) and deflections at moderate loads. The program could, however, not take yielding of the reinforcement into account and was therefore unable to predict the full load carrying capacities. Estimating behavior and capacity of a partly cracked wall with transverse loading and yielding in some of the reinforcement is still very difficult even with more advanced and complicated models and programs as Abaqus /Mehlsen, 2011/ and has not been achieved yet in a reliable manner.

### 3. JOINTS BETWEEN PREFABRICATED WALL ELEMENTS

The traditional joint design between prefabricated concrete walls consists of U-shaped stirrups reaching out from the two elements into the joint, where a vertical reinforcement bar is inserted to tie the two rows of U-shaped stirrups together before the concrete or mortar is cast in the joint. This activity is time consuming and may involve rough on-site bending or straighten of the U-stirrups (against the rules) and makes joint quality and strength major sources of uncertainty for the final structure safety. Easy to use joint designs may be a solution to these problems

Danish producers (EXPAN and The Danish Element producers association BEF) and universities (DTU Byg and ASE) have therefore been active in developing, testing and modelling a number of alternative joints in recent years. Alternative joint designs may involve inserts, SE-joints, wireboxes and other approaches. Testing is required in this situation necessary, first as a screening of the joints eventual suitability and later as documentation for performance.

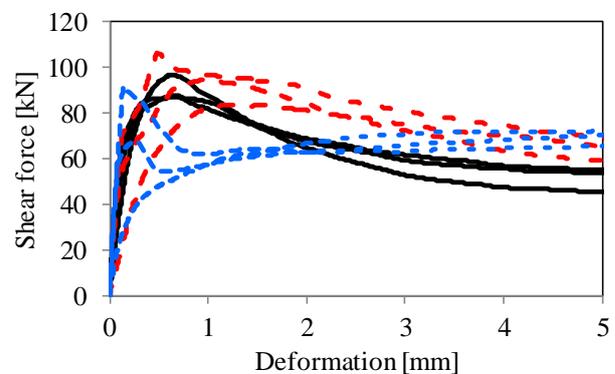


Figure 3 – Test bench (left) with test specimen and load-deformation relation for three different joint designs (U-stirrups and alternatives in a smooth joint) /Nielsen and Nordkvist, 2014/

A number of student projects /Andersen and Poulsen, 2002/, /Frederiksen and Madsen, 2011/, /Nielsen and Nordkvist, 2013/ /Christensen and Pedersen, 2014/ have focused on these problems, resulting in a large number of tests (113 large tests plus the material tests until now). The standard test element is app. 2,08m x 0,8-0,9m x 0,15m and shaped as two L-shaped standard parts, so the main difference between two different test series will be a) the surface in joints (toothed, partly toothed or smooth) or b) how elements are actually joined (glue, mortar or concrete and U-stirrups, SE-joints or wireboxes or something different). The test bench with a test element is shown in Figure 3. The tests have identified some good and some poor joint designs and form a good basis for further developments.

#### 4. CONCLUSIONS.

The use of lightly reinforced wall elements is safe and the capacity against transverse loads is quite sufficient to withstand the wind loads. It may seem safe to use yield line method, if one only compares estimated capacities to experimental capacities, but when the reinforcement ruptures before the peak load is reached, then it is doubtful to use that method.

The new and old designs of joints provide an added and valuable insight into the behavior of joints. This will undoubtedly lead to additional testing and further develop of new joint types.

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